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Sustainability performance for Brazilian electricity power industry: An assessment integrating social, economic and environmental issues

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ABSTRACT

The increased pressure on companies to address sustainability issues has resulted in the development of several voluntary corporate sustainability integration approaches. The array of existing approaches is large and overwhelming, resulting in companies not understanding what corporate sustainability really means for their businesses. Considering environmental, economic and social issues, this paper aims at assessing the performance of the Brazilian electricity power industry in terms of its sustainability performance. An analysis of Global Reporting Initiative (GRI) indicators for the energy sector lead to an assessment of its sustainability performance by applying Data Envelopment Analysis (DEA) specified with a directional distance function (DDF). Five scenarios were created: (i) Flexible weights; (ii) Triple bottom line; (iii) Social issues; (iv) Economic issues; and (v) Environmental issues. With considering (i) flexibility weights, almost all companies are efficient. We also found a significant difference when we compared (i) with the other four scenarios (ii, iii, iv and v). Taking into account the triple bottom line scenario (ii), the results indicate that companies were less efficient when compared with the flexible weights scenario (i). Taking into account the last three scenarios (iii, iv and v), only four companies were considered as providing top benchmarks in sustainability performance.

1. Introduction

During the last 30 years, globalization, environmental pollution, and the shortage of resources have led to an increase of stakeholder pressure on companies to expand their focus to sustainability, and responsible business performance in addition to financial performance (Leszczynska, 2012). This increase has resulted in the development of several voluntary approaches: tools, instruments and initiatives to support companies with the integration of corporate sustainability (CS) into their core business processes. For example: cleaner production, corporate social responsibility, sustainability reporting, environmental management systems, and corporate sustainability (for other approaches see Robèrt et al., 2002; Ness et al., 2007; Baumgartner, 2008; Lozano, 2012; Singh et al., 2012).

There are considerable differences among the approaches. For example, Lozano (2012) found that most focus on operations and processes, and management and strategy, followed by assessment and communication. With efforts having been made through combining two or more different approaches to extend the focus of analysis (Ness et al., 2007), none address all sustainability issues covering the full corporate system.

With the variety of CS integration approaches, serving as a basis for the decision-making on future actions, the consideration of the appropriateness of a course of action to a particular business situation is key (Medel-González et al., 2013). Moreover, these approaches aim to give support with tracking strategies on the three sustainability issues at all organizational levels (Medel-González et al., 2013).

Despite the attention from scientific and professional literature on the development of these approaches, there is a lack of clarity regarding the focus of the overall discussion and the use of the term 'sustainability' by these approaches (Glavic and Lukman, 2007; Sartori et al., 2014). Therefore, companies have to face the challenge and apply CS integration approaches that enable the combination of environmental, economic and social issue indicators into a single framework (Lozano and Huisingh, 2011). This integrated and multi issue perspective facilitates the understanding and comparative assessment of corporate sustainability performance (Lozano, 2013) and the presentation of results to decision-makers (Erechtchoukova and Khaiter, 2013).

The aim of this paper is to contribute to the understanding of corporate sustainability performance by assessing the efficiency of the

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electricity power industry in Brazil. It emphasises the importance of using quantitative methods to assess sustainability performance by using sets of indicators (Maxim, 2014) covering all three sustainability issues (i.e. social, economic and environmental). We applied the Data Envelopment Analysis (DEA) method specified with a Directional Distance Function (DDF) using sustainability indicators from GRI reports.

This paper also contributes to a better understanding of the current situation of the Brazilian power industry considering CS in different scenarios. Various initiatives have been created in Brazil to respond to CS issue demands, such as the Water Law (1997) and the Environmental Crimes Law (1998), a Business Council for Sustainable Development, the National Environment Program, the National Energy Plan (2030), the Rouanet Law (encouraging cultural investment) (1991), National Solid Waste Policy (2010) (MMA, 2008), showing that the increased focus of political actions on sustainability have an impact in both the Brazilian private and public sectors. Consequently, this paper also discusses policy implications for decision-makers.

The paper is organized as follows. First, we review the relevant literature on CS performance and integration approaches. Second, we present the method applied to develop this study. This is followed by the results and the discussion of the research outcomes in light of the literature. Finally, the main conclusions are drawn.

2. Theoretical background

Sustainability is a subject that is gaining greater attention in the academic field and in business. It becomes quite critical for the reported information to be comparable across companies that operate in the same industry or sector (Ng and Nathwani, 2012). For example, it is not possible to determine accurate values of reference for sustainability (Azar et al., 1996), apart from the process of quality control, making the determination of the relevance of information reported by companies in certain sectors a key challenge for sustainability reporting (Ng and Nathwani, 2012; Searcy and Elkhawas, 2012). Also, stakeholders have difficulties in measuring and assessing the actual extent of a firms' performance directly (Lee and Saen, 2012).

According to Bell and Morse (2008), to understanding sustainability it is required to recognize and work with unities. Even though one should not focus on the sustainability of isolated entities, but rather on the sustainability of entities as interconnected parts, it is still necessary within each area to develop a range of context-specific sustainability definitions, goals, indicators, etc. The multi-issue sustainability perspective contributes to making explicit the three principles underlying sustainable development: Environmental integrity; Social equity; and, economic prosperity over time (Gatti and Seele, 2014). Here, as described by Kajikawa (2008), the economy, the environment, and society are interlinked in the biosphere in a manner in which natural capital sustains the economy, which in turn supports quality of life - for example, health, security, and the pursuit of happiness.

2.1. Approaches for sustainability performance

Over the last 20 years, different initiatives related to environmental and sustainability performance of companies have been developed. The diversity of existing frameworks could appear as a business strength to achieve more sustainable business. Medel-González et al. (2013) describe two different reporting models related to environmental and sustainability performance: GRI and ISO 14031.

Sustainability reports are the primary mechanism through which corporations share information on their sustainability performance (Searcy and Elkhawas, 2012). This information consists of disclosures by corporations about how they manage the various issues related to sustainable economic development and on metrics designed to show their actual performance over time (Hess, 2014). Sustainability reporting has become popular and the Global Reporting Initiative (GRI) is the most used global guideline for corporate sustainability reports (Searcy and Elkhawas, 2012).

The disclosure of certain sustainability information can be an instrument for generating favourable impressions of an organization's sustainability performance, preserving organizational legitimacy, including the 'social license to operate', risk of regulatory mandates, and enhanced reputation, thus creating a potential improvement in productivity through technological innovation on environmental protection (Hahn and Lülfs, 2013; Wang et al., 2014).

The ISO 14031 standard provides guidance on the design and use of environmental performance evaluation within an organization. It describes two broad categories of indicators: (i) Environmental Performance Indicators (EPI): specific expressions that provide information about the environmental performance of an organization; (ii) Environmental Condition Indicators (ECI): to provide information on the environmental condition. This information can help an organization to understand the actual or potential impact of its processes on environmental issues, and thus support the planning and implementation of the environmental performance evaluation.

The key method for sustainability performance evaluation is the use of indicators (Dalal-Clayton and Bass, 2002). Indicators can help to identify, define, and communicate about sustainability issues, and they can be used to forecast and monitor the results of choices. Lozano (2012) found that most companies focus on operations and processes, and management and strategy, followed by assessment and communication. With efforts having been made through combining two or more different approaches to extend the focus of analysis (Ness et al., 2007), none addresses all sustainability issues covering the full corporate system.

Searcy and Elkhawas (2012) note that the development of sustainability indicators to meet established needs has been an endeavour of the academic literature, both at the firm and corporation levels. These indicators should correspond to the policies, strategies and goals of an organization, according to their business area, by providing key information for their corporate sustainability decision-making process (Medel-González et al., 2013).

For example, Krajnc and Glavic (2005) proposed an index to measure corporate sustainability by aggregating GRI indicators. The composite indicators are considered to be a good vehicle for helping to measure sustainable development and progress achieved in it (UNCSD, 2012). Starik and Kanashiro (2013, p.11) support the "exploration and development of sustainability solutions that are multi-level, systematically integrated (including their inputs, processes, outputs, and feedbacks), and multi-stakeholder oriented".

Monitoring progress towards an improved contribution to the sustainable development of society requires the identification of indicators that provide manageable units of economic, environmental and social conditions (Bohringer and Jochem, 2007). This implies that companies need to achieve mutually interdependent sets of issues: the Triple Bottom Line (TBL) of planet, people and prosperity; thus integrating economic, social and environmental issues (Elkington, 1998). According to Samuel et al. (2013) using indicators does not ensure sustainable operations, but rather the monitoring of performance and transparency in information dissemination with respect to TBL.

By constructing quantitative measures, it is possible to specify which sustainability aspects will be measured, which will be preserved or developed, and how these different aspects may be related or integrated. In summary, complexity, uncertainties and the interactions of economic, environmental, and social systems bewilder companies regarding their actions and decisions on the path to sustainability. This complexity calls for new approaches to corporate sustainability, bringing on board stakeholder interests (Garcia et al., 2016). In the next section we provide models for integrated performance assessment at the company level.

2.2. Overall measure of performance

The history of characterizing performance dates back a few decades, and shows methods that make use of artificial intelligence and statistical models, while there are efforts to standardize and group them together in a consistent manner (Bennett et al., 2013). The modeling can provide understanding, visualization, and important communication tools (Voinov, 2008).

Boulanger and Bréchet (2005) present six types of modeling often used in policy formulation and decision making, namely: macroeconometric models; computable general equilibrium models; optimization models; models of dynamic systems; probabilistic network models or Bayesian models; and multi-agent simulation. The first three types are economic or traditional models in engineering. The last three are less common, except the model of dynamical systems, which is common in the environmental and natural resource management area. These models, using a mathematical and statistical basis, seek to systematize, measure, compare, and represent various aspects of sustainability (Todorov and Marinova, 2011).

In the field of evaluation, the models are usually constructed to satisfy one or more of the five main objectives according to Kelly et al. (2013): Systems Dynamics; Bayesian Networks; Couple Component Models; Agent-Based Models; and Knowledge-Based Models. In order to choose the most appropriate approach for a particular case, it is important to consider the resources available for the analysis of the problem and the desired level of accuracy of the results (Jain, 1991).

Systems dynamics is a method for studying and managing complex systems. It "combines the theory, methods, and philosophy needed to analyze the behavior of systems in not only management, but also in environmental change, politics, economic behavior, medicine, engineering, and other fields" (Forrester, 1993). The following are some examples of models related to sustainability assessment: i) IIASA's air pollution model (RAINS); the IMAGE model (created to analyze social, biosphere, and climate system dynamics); and iii) the Wonderland model designed to illustrate economic-environmental interactions (Ness et al., 2007).

Agent-based models are useful in the representation of the interactions between systems (for example, human or animal groups), in which processes are exploited and shared (Kelly et al., 2013). Since this interaction is typically non-linear, the system's behavior cannot easily be deduced from individual behavior, i.e. macro-level behavior is not equal to the simple aggregation of micro-level behaviors (Lovrić et al., 2013). Systems dynamics models and agent-based models are similar, since they are intended to improve the understanding of the system and the social learning.

Knowledge-based, or conceptual models are useful as an input point for models previously mentioned. The goal of conceptual models is to understand the characteristics of a system, as well as identify the variables and factors that are part of this system (Kelly et al., 2013).

Bayesian Networks are mathematical models that can be used to describe complex systems, in particular the key factors and interactions of the system and the nested systems within larger systems (Buys et al., 2014); Bayesian Networks provide the means to integrate information within a sound statistical modeling framework (Johnson and Mengersen, 2012) that can be used by, for example, an environmental manager. And the last model cited by Kelly et al. (2013) is couple Component Models that involves combining models from different disciplines or sectors to come up with an integrated outcome.

In the context of management and decision-making under uncertainty, which is relevant to this study, there is a set of multi-criteria methods, originated from operations research, which assist in the process of decision making, such as to: aid cost-effective analysis of resource allocation; address conflict resolution; aid traffic planning; etc. (Saaty, 1991). It is also relevant to highlight that, among the various multi-criteria methods for decision support, we have: i) the additive models, which generate a single criterion synthesis (for example, Analytic Hierarchy Process-AHP); ii) the classification methods (for example, Prométhée); and, iii) the methods of linear programming (for example, Data Envelopment Analysis).

Data Envelopment Analysis (DEA) evaluates the relative efficiency of decision-making units (DMUs), with multiple performance factors which are grouped into outputs and inputs (Seiford and Zhu, 2005; Hua and Bian, 2007). Once the efficient frontier is determined, inefficient DMUs can improve their performance to reach the efficient frontier by either increasing their current output levels, or decreasing their current input levels. However, both desirable (good) and undesirable (bad) factors may be present (Seiford and Zhu, 2005).

The previous approaches to performance analysis only consider desirable outputs. In the production process, undesirable outputs are usually jointly produced with desirable outputs. In this paper, we propose an approach for measuring sustainability in the presence of desirable and undesirable outputs simultaneously.

Furthermore, in this paper, a Data Envelopment Analysis (DEA) is applied to a case study: to analyze activities and to describe the relative level of CS performance of a specific company compared to other companies in the same industry. The application of the DEA model contributes to the understanding of CS integration development. A complex system consisting of factors that affect the system and their interactions, is so multidimensional and complicated that it is impossible for a human to keep track of the resultant processes. The alternative approach is an overall measurement of performance with interlinkages between their parts (here indicators).

3. Method

The first part of this section describes the Data Envelopment Analysis based on a Directional Distance Function model. In the second part, we describe the procedure for data collection and the definition of variables. Subsequently, we provide an outline of the Brazilian energy industry.

3.1. The Data Envelopment Analysis Model (DEA)

Data Envelopment Analysis (DEA) is a non-parametric method based on linear programming to assess the relative efficiencies and inefficiencies of decision-making units (DMUs) producing outputs by using inputs. DEA was first proposed in the pioneering paper by Charnes, Cooper and Rhodes (Charnes et al., 1978). It is used to estimate the technical efficiency of a DMU with constant returns to scale (CRS) in the frontier of the production possibility set.

The extension proposed by Banker et al. (1984) generalized this assumption and formulated the so-called BCC model, which exhibits variable returns to scale (VRS) at different points in the production frontier that would be obtained. In both models, an inefficient DMU can improve its performance by increasing the levels of outputs or decreasing the levels of inputs.

In the literature, the Data Envelopment Analysis (DEA) has been used for sustainability performance analysis. To give a few examples, Gerdesse and Pascucci (2013) used basic DEA models to assess the sustainability of a regional agricultural system under five scenarios. These scenarios reflected preferences with respect to the importance of the three dimensions of sustainability, with the option for relative weights assigned to inputs and outputs. In spite of the scenario analysis, the authors worked with a variable returns to scale model (VRS) and a constant returns to scale model (CRS).

However, real world applications may involve both desirable and undesirable outputs and inputs, and the resulting DEA model standard does not reflect the true production process (Hua and Bian, 2007). The introduction of the Directional Distance Function (DDF) approach, originally developed by Chambers, Chung and Färe (1996), is capable of expanding desirable outputs and contracting inputs/undesirable outputs simultaneously (Fang et al., 2005; Zhou et al., 2012; Zhang and

Choi, 2014). The application of the DDF approach extends the efficiency perspective by addressing one or two dimensions of sustainability. For example, Beltrán-Esteve et al. (2017) proposed the use of Life Cycle Analysis (LCA), a metafrontier and DDF to assess technological and managerial differences in eco-efficiency between production systems. Li et al. (2017) investigated the effect of environmental regulations on Chinese industry. In another study Zhang and Chen (2017) investigated the sustainability characteristics, including environmental efficiency, the shadow price of pollutants, and substitutability among inputs and outputs. Molinos-Senante et al. (2016) estimated the shadow price of leakages as a proxy of their environmental and resource costs.

Our study applies the DDF approach by addressing all three TBL sustainability issues (i.e. economic, environmental and social) at the same time to provide an overall measure of performance. Zanella et al. (2015) proposed an aggregation of the individual indicators in an overall measure of performance, derived of the DDF model of Chambers et al. (1996), as shown in (1). This model is used in this paper to assess the companies.

$$\overline{D}^{t}(\mathrm{y},\,\mathrm{b};\,\mathrm{g}) = \max\beta \tag{1}$$

$$s.\ t.$$

$$\sum_{j=1}^{n} y_{rj}.\ \lambda_j \geq y_{rjo} + \beta.\ g_y \quad r = 1, \ldots, s$$

$$\sum_{j=1}^{n} x_{kj}.\ \lambda_j \leq x_{kj0} - \beta.\ g_x \quad k = 1, \ldots, l$$

$$\sum_{j=1}^{n} b_{kj}.\ \lambda_j \leq b_{kj0} - \beta.\ g_b \quad k = 1, \ldots, l$$

$$\sum_{j=1}^{n} \lambda_j = 1$$

$$\lambda_j \geq 0 j = 1, \ldots, n$$

In formulation (1), $b_{kj}(k = 1, \ldots, l)$ are the indicators that should be reduced for DMU j(j = 1, …, n), and $y_{rj}(r = 1, \ldots, s)$ are the indicators that should be increased. The λ_j are the intensity variables. The components of vector $g = (g_{y,} - g_{b)}$ indicate the direction of change for the indicators. Positive values for the components are associated with expansion to the original levels and negative values are associated with contractions. The factor β indicates the extent of DMU's inefficiency and corresponds to the maximal feasible expansion of desirable indicators and contraction of undesirable indicators that can be achieved simultaneously.

According Chung et al. (1997), the factor β can be converted into a measure of efficiency ranging from 0 to 1 for each DMU. When the directional vector is specified as the current value of the indicators for the company under assessment, i.e., $g = (g_y; -g_b) = (y_{rj0}; -b_{kj0})$, the directional distance function is comparable to the Shephard's output distance function and thus the efficiency measure is given by 1+β*. This value ranges between zero and one, where zero corresponds to the best level of performance observed in the sample.

As by-products of the efficiency assessment using model (1), it is possible to identify the peers (benchmarks) for each inefficient DMU and the targets that the inefficient DMUs should achieve in order to become efficient. The peers for the DMU j_0 under assessment are the DMUs with values of λ_j^* greater than zero at the optimal solution of model (1).

The flexibility in the choice of weights in model (1), which is a strength of a DEA analysis, may also be a weakness, as it allows some indicators to be assigned a zero weight. This means that these factors are in fact ignored in the performance assessment. In cases where there is interest in reflecting the relative importance of different indicators as perceived by decision makers, this information can be easily incorporated into the DEA model by imposing restrictions to indicator weights.

In the context of this paper, we assess companies in a first moment allowing for complete flexibility in the definition of the weights, to give them the benefit of the doubt in the assessment. This implies that they can be considered efficient if they excel in a particular aspect represented by the indicators used in the model. We term these 'Scenario flexibility weights'.

In a second moment, we imposed restrictions on the model to reflect different points of view regarding the relative importance of the different indicators and dimensions. The weight restrictions were imposed to the dual of model (1). The dual formulation shown in (2) facilitates the incorporation of weight restrictions in the model

$$\boldsymbol{min} - \sum_{r=1}^{s} \boldsymbol{y_{rj0} u_r} + \sum_{k=1}^{l} \boldsymbol{b_{kjo} p_k} + \boldsymbol{v} \tag{2}$$

$$s.\ t.$$

$$\sum_{r=1}^{s} g_y u_r + \sum_{k=1}^{l} g_b p_k = 1$$

$$-\sum_{r=1}^{s} y_{rj} u_r + \sum_{k=1}^{l} b_{kj} p_k + v \geq 0$$

$$j = 1, \ldots, n$$

$$u_r \geq 0 \quad r = 1, \ldots, s$$

$$p_k \geq 0 \quad k = 1, \ldots, l$$

$$v \in \mathscr{R}$$

The weight restriction are formulated as shown in (3), were proposed by Zanella et al. (2015), and represent the proportion of total weight that should be associated with each indicator, including desirable (y_r) and undesirable (b_k) indicators. They ensure that all indicators contribute to the overall performance measure and allows expression of their importance as a percentage.

$$\begin{cases} \dfrac{u_{r0}\overline{y}_{r0}}{\sum_{r=1}^{s} u_r \overline{y}_r + \sum_{k=1}^{l} p_k \overline{b}_k} \geq \omega_{r0} \\ \dfrac{p_{k0}\overline{b}_{k0}}{\sum_{r=1}^{s} u_r \overline{y}_r + \sum_{k=1}^{l} p_k \overline{b}_k} \geq \omega_{k0} \end{cases} \tag{3}$$

$$r_0 = 1, \ldots, s$$

$$k_0 = 1, \ldots, l$$

The restrictions (3) are based in DMU artificial whose indicators are equal to the average value of each indicator in the sample. For the DMU artificial DMU, the virtual weight of the desirable indicator $(u_{r0}\overline{y}_{r0})$ or undesirable indicator $(p_{k0}\overline{b}_{k0})$ divided by the virtual weight of all indicators must be at least a certain percentage value ω_{r0} or ω_{k0}.

So, in the second scenario, considering TBL, we use a different system of weight restrictions in the assessment of the companies: (a) the weight given is 0.3333 (1/3) to each sustainability issue, ascribing the same importance to each one; and, (b) the minimum weight given is 1% (0.01) for each indicator, to prevent an indicator with bad performance being ignored.

In the last stage phase, we created scenarios iii, iv and v. The aim is to give more importance to each sustainability issue, i.e., emphasis on the social, on the economic, and on the environmental, respectively. For example, the third scenario identifies an emphasis on social issues, and allocates a minimum of 55% of the total weight to the sustainability issue, while the economic and environmental allocates a minimum of 10% of the weight to each one. There is 25% of the total weight that can be freely allocated, using optimization.

Therefore, in making business decisions, we try to find the balance among the environmental, social and economic dimensions. In this way, we worked with different systems of weights in order to give more importance to economic, or environmental, or social, or to give equal importance to all three sustainability issues (i.e. scenario ii).

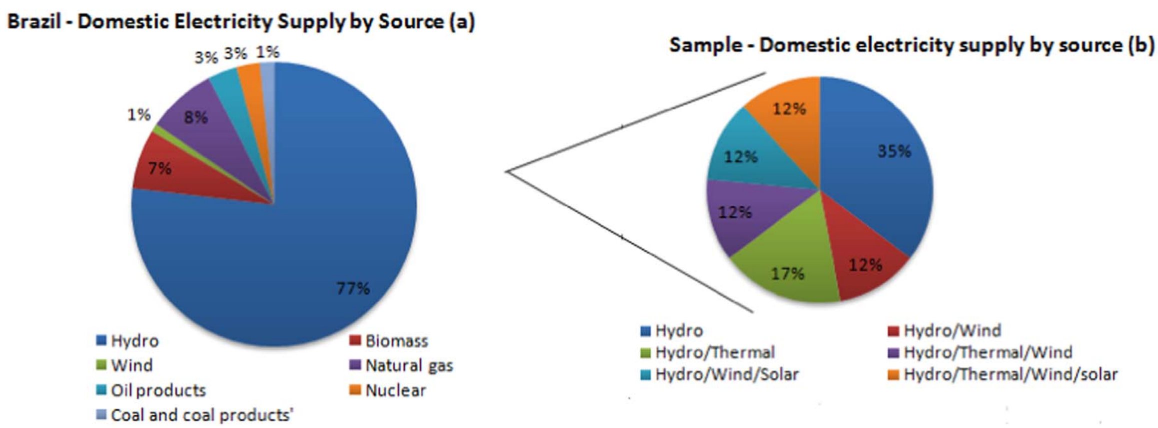

Fig. 1. Domestic Electricity by source for Brazil (a), and sample (b).
Source: (a) EPE (2013), (b) by authors

3.2. Data description

Brazil has been prominent in the international scene due to the strong presence of renewable sources within its energy sector. Brazilian Energy Balance shows that such sources represented 41% of the country's domestic energy supply in 2013, whereas the world average was 13% and for OCDE countries it was 8,1% (EPE, 2014).

Electricity generation in the Brazilian public service together with self-producers' power plants reached 552,5 TW h in 2012, a figure 3.9% higher than the 2011 results (EPE, 2013). The public service plants remain the main contributors, with 85.9% of total generation. The main source is hydropower, although there was a decrease of 2.6% compared to the previous year. The electricity generation from fossil fuels correspond to 16.7% of the national total, compared with 11.9% in 2011. The self-producer generation in 2012 contributed 14.1% of total production, considering the aggregate of all sources used.

The Fig. 1(a) shows the structure of the domestic supply of electricity in Brazil in 2012. Brazil has an electricity matrix predominantly renewable, and the domestic hydraulic generation represents 77% of the supply (EPE, 2013). The situation in Brazil is different from the worldwide situation. In 2012, 67.7% of world electricity production was from generating plants burning fossil fuel; hydroelectric plants provided 16.5%; nuclear plants 10.8%; biofuels and waste 1.9%; while geothermal, solar, wind and other sources made up the remaining 3.1% (OECD/IEA, 2014).

The sample case (Fig. 1b, divided into six categories) presents an electricity matrix predominantly renewable, represented by 59% the companies in analysis. The thermal power plants are fired by biomass, natural gas, petroleum derivate and nuclear. In many regions, we have a possible link between the availability of wind and sunshine, heat and power. Such combinations can occur on different timescales: short term during the day (sunny days may be less windy), and on a seasonal level (autumn may be windier, summer sunnier). Similarly, water availability in hydro plants often shows seasonal variations. Finding the right mix of technologies can thus balance the variability in each component, leading to a mix that matches the demand for electricity more closely.

To assess the sustainability performance of the Brazilian Electric Energy Industry, we gathered data from GRI reports published in 2013 (referring to the year 2012). The GRI guideline provides a list of 79 performance indicators covering the three sustainability issues. In order to identify the indicators reported, we read all the reports and recorded the indicators presented. The exact data used for each indicator in the reports was recorded in a database spreadsheet leading to the development of a database of all indicators used.

To assess the three sustainability TBL issues, we selected the indicators in order to fulfil two conditions: (i) the indicators that are material (disclosed) to measuring the sustainability performance; and (ii) availability of information for all the units of analysis we are considering in this research (thus, the variables with missing data, and zero values were omitted).

Following this, 6 common variables were put together, resulting in three new indicators. In most cases, those indicators were reported as the only value for the companies as it addresses the compliance, energy aspect and emission aspects. The indicators are “fines (compliance aspect)”, “energy consumption (energy aspect) and ”total emissions (emission aspect)”.

In Table 1 we present the indicators available for 17 companies that were selected to assess their CS performance. To provide a measure of impact independent of the scale of operations, we examined some parameters (G2, G3, B2, B3, B4, and B5) based on ratio indicators, according to a literature review described in column 3 of the Table. For example, the unit of greenhouse gas emissions per unit of electricity generation is a good measure of the environmental issue according to

Table 1
Definition of the variables.

Abbreviation Code	Desirable indicator	Theoretical basis
G1	Hours of training per year per employee	Gerdessen and Pascucci (2013)
G2	Infrastructure investments and services provided primarily for public benefit / economic value generated	Krajnc and Glavič (2005)
G3	Research and development (R & D) expenditure / economic value generated	Kayal (2015)
Abbreviation Code	**Undesirable indicator**	**Theoretical basis**
B1	Rates of injury	GRI (2011)
B2	Total monetary value of fines / total electricity generation	Oliveira et al. (2008), Duzgun and Komurgoz (2014), Mainali and Silveira (2015)
B3	Total energy consumption / total electricity generation	ICHEME (2005), Andrade Silva and Guerra (2009)
B4	Total water withdrawal / total electricity generation	Feng et al. (2014), Liu et al. (2015)
B5	Total greenhouse gas emissions / total electricity generation	Feng et al. (2014), Begic and Afgan (2007)

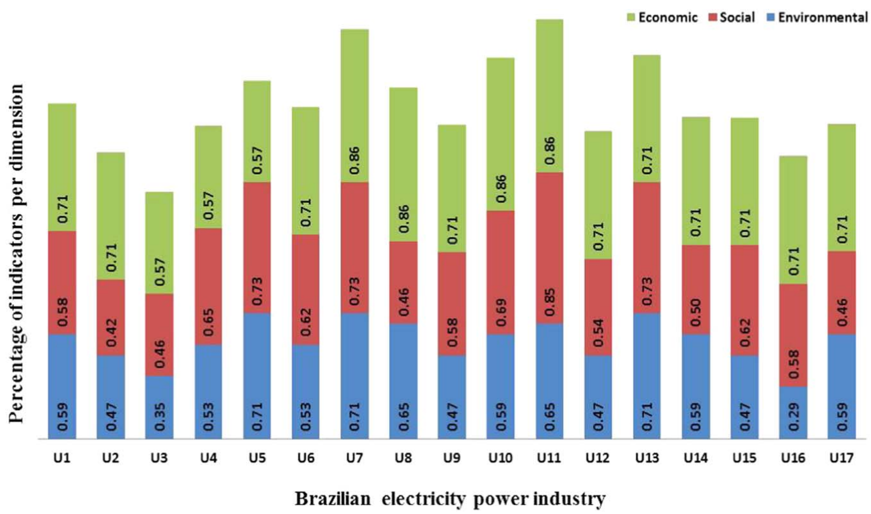

Fig. 2. Percentage of GRI indicators used by companies in each sustainability issue.

Feng et al. (2014) and Begic and Afgan (2007).

4. Results

This section is divided into two major parts. The first part presents the indicator disclosures regarding the sustainability issues. And in the second part, we present the results in order to reflect on different points of view from the different scenarios.

4.1. GRI description

The results of our GRI indicators can be seen in Fig. 2. Only two companies (U7 and U13) disclose more than 70% of the indicators in corresponding to the three sustainability issues. There is preponderance in the use of economic indicators, ranging from 57% to 86% in the use of indicators proposed by the GRI. This can be associated with the fact that many of these indicators are already used in traditional financial reports. According Delmas and Blass (2010), financial performance is well defined and very structured (for instance return on assets and return on investment), while social and environmental performance are quite heterogeneous.

The use of environmental and social indicators varies, from 29% to 71%, and 42–85%, respectively. The results show that there are missing values, making it difficult to compare the performance of companies in relation to various aspects and sustainability indicators. Consequently, 8 indicators were selected in order to assess the sustainability performance with a Data Envelopment Analysis (DEA) specified with a Directional Distance Function (DDF), according to Table 2.

The set of indicators is represented by the descriptive measures in terms of average, minimum and maximum values and standard deviation.

Considering the sample of 17 companies for the year 2012, we note that there are significant variations in all the variables, which might be an indication of an uneven concern for environmental, economic, and social factors between the different companies.

Table 2
Summary statistics of the indicators.

Variables	Mean	Minimum	Maximum	Std. Dev
G1	51.2941	7	134	32.49
G2	1.4677	0	6.7441	2.33
G3	4.4793	8.94E−04	54.8092	13.062
B1	2.1765	0	5.25	1.84
B2	0.1181	0	0.6929	0.20
B3	0.0666	5.47E−04	0.3173	0.082
B4	0.7667	1.38E−04	9.1317	2.22
B5	0.1300	2.12E−05	0.7109	0.199

We can also note that indicator B3 - Total energy consumption/total electricity generation has a minor difference (i.e. small standard deviation) showing that the energy efficiency of the 17 companies is fairly equal. Finally, we can note that there are two indicators with a major difference (i.e. high standard deviation) in "Hours of training per year per employee – G1″, and "Research and development (R & D) expenditure – G3″, considering the magnitude of the maximum and minimum values. With G1 and G3 representing the majority of the desirable indicators, the alteration between their maximum and minimum values ask for more in-depth or longitudinal data collection among Brazilian energy companies.

4.2. Performance measures

The following information involves the application of DEA specified with the DDF model in relation to TBL/sustainability issues. Table 3 shows the five scenarios used to analyze the sustainability performance of the companies, with the average, minimum and maximum values. Also, the assessment that ranked companies according to their sustainability score show a slight difference in the scenarios; presented in Appendix A. The performance is restricted to a range from 0 (better performance) to 1 (worse performance).

Considering the flexibility in the choice of weights (i.e. scenario i), 11 companies obtained the maximum efficiency score and 6 companies were considered inefficient, where the average level of efficiency is 0.1217. According to Sarkis (2007), the DMU, where one particular ratio of an output to an input is highest, will assign all its weight to

Table 3
Performance assessment of electricity companies in different scenario.

	Scenario	Weights assigned			Best efficiency	Average	Min. - Max.
		Env.	Econ.	Social			
i	Scenario Flexibility	0	0	0	11	0.1217	0 – 0.97
ii	Scenario triple bottom line[a]	0.333	0.333	0.333	6	0.4253	0 – 1.00
iii	Scenario Social[a]	0.1	0.1	0.55	8	0.3018	0 – 1.00
iv	Scenario Economic[a]	0.1	0.55	0.1	6	0.4081	0 – 1.00
v	Scenario Environmental[a]	0.55	0.1	0.1	6	0.3675	0 – 0.99

[a] The minimum weight is 1% for each indicator.

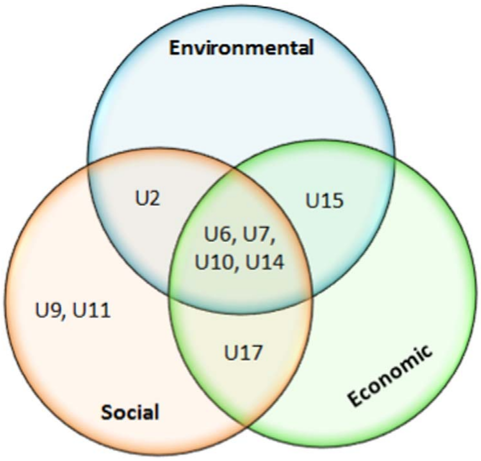

Fig. 3. Summarized performance score results of the 17 companies.

those specific inputs and outputs to appear efficient. Thus, there is irrefutable evidence that 6 companies are performing worse.

In the second scenario of the analysis (i.e. TBL scenario), we find that 6 out of 17 companies (i.e. about 35% of all DMUs) are labelled as efficient, and the average is 0.4253. Comparing the (i) and (ii) scenarios, we find few companies with good performance in the second scenario, also the average is higher than the flexibility scenario. This means almost all companies are efficient in the 'flexibility' scenario.

The results for the last three scenarios are quite similar to the triple bottom line scenario. But there are more efficient companies in the scenario 'social' with a smaller average score. According to Fig. 3, we identified four companies that can be considered as top benchmarks in sustainability, according to the point of intersection of the Venn diagram fields. Also, the economic and environmental scenarios are more similar to the triple bottom line scenario in terms of average and the number of efficient companies.

The mean value of the last three scenarios, iii, iv and v (0.3018, 0.4081 and 0.36747), indicates also that there is scope for improving the companies' operating practices resulting in performance enhancement. The remaining companies can only be considered benchmarks in a single scenario, social emphasis; for example U9 and U11. Also, U2 has a low performance (0.03) in the economic scenario and is efficient in the other scenarios. Company U15 is efficient in the economic and environmental scenarios, but presents low performance for the social and triple bottom line scenarios.

An examination of the companies with efficiency scores (U2, U6, U7, U10, U14 and U17) reveals which firms have the proper activities or behavior to enhance their corporate sustainability. These companies present good performance, depending on the model used.

The U2, U6, U7 and U10 companies have electricity generation based only on hydropower stations, while U14 and U17 have a share of renewable energy from hydropower plants (around 80%) and non-renewable energy from thermal stations.

In the benchmarks analysis (Appendix B - Peers), i.e., the companies that appear at the top of the ranking irrespective of the scenarios, while the companies considered effective are referrals from the other companies considered inefficient. The higher the value of the parameter λ_k, the more important is the efficient DMU, acting as excellent benchmarks in comparison with inefficient companies. Companies U7 and U14 are considered the best partners of excellence for the inefficient DMUs, i.e., appear more frequently as benchmarks.

The most important factor for the better performance of U7 and U14 are 'hours of training per employee', following 'their water and energy consumption', respectively. Also, 'research and development (R & D) expenditure' was a differential factor for these companies.

Finally, we would like to point out that one company (U11) has good performance on 'greenhouse gas emissions', and only one other company has good performance (U6) on 'infrastructure investments and services provided primarily for public benefit'. From this perspective, once the production process appears to involve a lower consumption of natural resources, such companies may lose the attention of society.

As highlighted, the top 5 companies (U16, U8, U3, U5 and U1) had the worst efficiency scores. The most important factors for the inefficiency of these DMUs are: (i) a lack of infrastructure investment, and services provided primarily for public benefit; (ii) low investment in research and development (R & D); and (iii) a high rate of greenhouse gas emissions.

Analysing these factors, we could imply that the reasons for this inefficiency can be related to the characteristics of Brazilian Electricity Industry, such as systemic corruption, lax regulation enforcement, and lack of social pressure. The three factors of the inefficiency mentioned in the above paragraph will be further discussed within item 5, and will be related to some new actions: i) to focus more on private incentives for infrastructure investments and services provided primarily for public benefit; ii) to establish plans to increase and diversify Brazilian's energy mix; and, iii) the creation of new tax incentives that enable legal entities to invest a part of their payable income tax in cultural activities.

5. Discussion

This section presents both the discussion of the main findings in light of the literature, and discussion of policy implications.

5.1. Discussion of the main findings

Our study uses a multidimensional construct, which is based on economic, environmental and social indicators, to investigate the performance determinants for the companies. DEA specified with a directional distance function (DDF) offers insights regarding performance improvements considering the joint production of desirable and undesirable indicators, such as pollutants. Thus, the flexibility of DEA is such that by adding relatively simple constraints, significantly different scenarios can be provided without losing too much in terms of complexity and sophistication on the conceptual side (Gerdessen and Pascucci, 2013).

To have a better assessment of the sustainability, we need take into account how sensitive the results are to changes in each scenario. We start our discussion looking at the unweight restrictions scenario, i.e., total flexibility in the selection of weights assigned to indicators. Considering this scenario, 11 companies obtained maximum efficiency scores. Under these conditions, for the companies that do not achieve the maximum score, even when using the set of weights that maximises their efficiency, there is irrefutable evidence that other companies are performing better.

Under the scenario of unweight restrictions, some indicators are in fact ignored in the performance assessment. Then, we look at the different weight restrictions scenarios. One objective for using weight restrictions is to make the model more discriminating in assessing the performance of companies. This represented a challenge to us (or decision makers), to explain why particular weight restrictions were used, since efficiency deteriorated compared to the model without the weight restrictions. So, the information relating to the importance of the individual dimensions ensures that the companies are evaluated under similar conditions enabling a fair comparison. Also, to ensure that the companies observe economic, environmental and social issues (the "triple bottom line"), we use a similar system of weighting.

Using the weights allocated by the company to each indicator and to each dimension, we can identify the areas with better performance. The results show that there are small differences in sustainability performance under different scenarios, i.e., economic or environmental dimensions are not very sensitive when choosing the weights assigned. However, the restrictions chosen for each scenario indicates two important implications.

First, the average value of the TBL scenario is superior to the average value of other scenarios. This means that by focusing the improvements in all indicators simultaneously, we end up further from better performance. Also, some dimensions have more impact on the results than others. Second, the analysis developed in this research allowed the identification of the performance in specific dimensions, i.e., identified the sustainability issues that have an unbalanced potential for improvement.

Specifically, among the 17 companies analysed, the results allowed us to identify at least 16 companies that should pay greater attention to reducing greenhouse gas emissions. This fact shows that in assessing sustainability performance we should consider all production factors and related impacts, not only desirable results.

Electricity, a major form of user energy, is used to power homes, businesses, and industries (Gómez-Calvet et al., 2014). The combustion of fossil fuels for electricity generation is the largest source of carbon, accounting for more than 40% of global CO_2 emissions (Lira-Barragan et al., 2014). That is, the electricity generation industry clearly plays a critical role in reducing global CO_2 emissions.

Brazil has faced up to climate change. In particular, special attention has been given to greenhouse gas emissions since the Climate Change Brazilian Policy was established by Act 12.187/2009, regulated by Decree 7.390/2010, and the environmental regulation of production processes has been stipulated nationally (MMA, 2008).

Unfortunately, as a consequence of the unfavourable hydrological conditions, there was an increase in the greenhouse gas-effect emissions. For example, regarding the emissions from electricity generation in the National interconnected Power System in 2014 there was an increase of 82.5% over the level observed in 2012 (ANEEL, 2014).

On the one hand, an increase in renewable energy sources represents a guarantee in the long term to mitigate climate change. On the other hand, renewable energy sources are dependent on weather conditions and may suffer because of unfavourable conditions (Schaeffer et al., 2008). To place the debate in its proper context, in the 1970s and 1980s, realizing the massive potential of Brazil's rivers, the government began large-scale investments in hydropower (EPE, 2007). However, since the early 2000s, stability of supply and expansion through a diversification of sources has been among the government's priorities in electricity policy.

At this moment, it is widely accepted that the diversification of the Brazilian generation mix is not a policy choice, but mainly a result of the restrictions on the hydropower potential. Over recent years, natural gas-powered thermal generation has seen a rapid increase, as it is being increasingly used (together with non-hydro renewables) to compensate for variations in hydropower generation (EPE, 2014).

According Santos et al. (2013), for example, in the period from 2008 to 2010, due to higher demand for thermal generation on account of hydrological conditions, even 8 nuclear power plants were not enough to meet the entire need for thermal complement and the ONS dispatched more natural gas plants. About the future, several current trends are pointing towards deterioration in Brazilian sustainable energy performance (Schaeffer et al., 2008; Santos et al., 2013; Luomi, 2014). These authors generally mention the carbonization of its electricity sector, stagnating energy efficiency performance, and a growing demand for fossil fuels. Industrial activities, the expansion of the agricultural sector, and the urbanization process that degrades water resources, destroys forests and pollutes the atmosphere, are examples of the ways in which economic activity jeopardizes the environment (Pereira et al., 2011).

Furthermore, strong growth reflects concomitant increases in economic growth, industrialization and mechanization of agriculture, population and urbanization, in patterns traditionally consistent with economic development. At present, the major end-users are industry (39.8%), residential (27%), commercial (18.1%) and rural (5.1%) (EPE, 2014).

According Wang et al. (2013), energy technological change appears to play a more significant role. For instance, if a company puts more effort into absorbing and utilizing advanced production technology, it will therefore make the greatest progress in energy technological improvement. Similarly, Fallahi et al. (2011), Sarkis and Cordeiro (2012), Sueyoshi and Goto (2013) and Gómez-Calvet et al. (2014) all suggest that it is possible to improve the performance of electricity companies through: (i) innovations in organizational practices and technological solutions that help achieve joint technical and environmental performance efficiencies; (ii) regulation of undesirable outputs; (iii) environmental policies; and, identifying drivers for efficiency improvement.

In addition, Ramos-Real et al. (2009) and Tovar et al. (2011) confirm that the productivity evolution of the sample companies, during the whole period, depended on the frontier shift; i.e. technical change that was mainly due to technological innovations. In contrast, Fallahi et al. (2011) pointed out that the low growth of productivity changes is related to low efficiency and non-changing technology. Therefore, it is necessary to renovate and modernize the current electricity generation processes. Moreover, the pollutant emissions and water consumption are related to machinery and equipment used.

Wang et al. (2014) note that technology innovation can reduce the amount of undesirable outputs (CO_2 in the case of this study), and in turn, increase efficiency. However, by considering Noble Energy Inc. for two years (2012 and 2013) their investment did not produce an immediate change in CO_2 emissions. Rather, this limited effect implies a necessity for investment from a long-term perspective. In addition, green investment for reducing GHG emissions is essential for corporate survivability in a global market, where companies must compete with each other in domestic and international markets.

Even if there is quite some heterogeneity across companies, our research shows that only very few companies are actually investing in research and development to jointly find sustainable and innovative solutions. In such context, Keen et al. (2005) argued that the social capacity for environmental management is developed jointly by the government, firms, and civil society.

5.2. Discussion of policy implications

The discussion of the research findings implies the following four possible policy implications.

First, the Brazilian government should focus more on private incentives for infrastructure investments and services provided primarily for public benefit. Starting in 2012, Brazil's government established plans to increase and diversify its energy mix, with goals to invest approximately $235 billion and install 36 Gigawatts (GW) of hydropower, 12 GW of biomass, and 11 GW of wind over the following 10 years (Brasil, 2015). As a result, the Brazilian energy balance is expected to keep its significant share of renewables sources of 45.2% in 2024.

As another example, the Rouanet Law, regulated by Decree number 1.494 on May 17, 1995, is the main financing mechanism for Brazilian culture and support for cultural projects (Brazilian Cultural Ministry, 2015). The main feature of the Rouanet Law is the tax incentives that enable legal entities to invest a part of their payable income tax in cultural activities. This is beneficial because of the income tax relief and it also allows them to sponsor a cultural event that can promote the company's brand.

Second, to improve sustainability performance, the Brazilian electricity companies need to put more effort into reducing greenhouse gas emissions. For this to work, industrial activities may be regulated by governmental agencies through rigorous laws and higher taxation. It is insufficient merely to pass laws, compliance needs to be enforced.

Third, an implication of this discussion is that, company decisions should be made by choosing from the available primary sources (coal, nuclear, natural gas, oil, and renewable sources) those that provide a better fit for efficient performance. Brazil might choose to encourage the use of renewable sources beyond hydropower, which might limit the use of thermal energy. So, before governmental policies that can create incentives on tax, energy companies can significantly change how to implement electricity generation and investment decisions to create positive effects, and, also, ensure the improvement in the quality of life of the population

Finally, as discussed by Sueyoshi and Goto (2012), these types of DEA empirical studies need to use comprehensive DEA approaches to obtain policy implications for guiding a large electricity generation industry. We hold that this analysis sanctioned our approach to assessing the indicators in the best possible light by introducing scenarios and forms to reveal actual sustainability performance. Moreover, this research allowed several improvements of the electricity system: (i) the major strengths and weaknesses identified in each scenario; (ii) assessment of the overall state of sustainability and of each issue; (iii) assistance for industry to anticipate and adapt in order to face the challenges of the future; an, (iv) the use of data to facilitate critical examination and discussion about sustainability performance, based on mathematical models.

6. Conclusions and policy implications

This paper presents a DEA model for assessing sustainability illustrated by data from the Brazilian electricity power industry. The results contribute to the definition of the sustainability performance of companies, and promote its improvement. The indicators used to measure sustainability were defined based on GRI. GRI is based on the broad concept of TBL including environmental, social and economic issues.

More specifically, this research emphasises the importance of using a quantitative method to assess the sustainability performance by using sets of indicators covering all three sustainability issues (i.e. social, economic and environmental). We show that the sustainability of Brazilian electricity performance could be measured and analysed through indicators based on GRI indexation, and using different scenarios. Seeking to achieve a sustainable and balanced view, in order to improve its sustainability, our results show some important directions.

First, we could perceive preponderance in the use of economic indicators, ranging from 57% to 86% in the use of indicators proposed by GRI. As pointed out before, this can be associated with the fact that many of the GRI's indicators are used in traditional financial reports. Also, our descriptive statistics indicate that social and environmental issues present a broader range (42% until 85% and 29% until 71%, respectively) therefore, companies systematically disclose an incomplete picture of how their activities affect society.

Considering the analysis of the sustainability performance of the companies, our findings show a slight difference in the different scenarios (i.e. TBL scenario, social scenario, economic scenario, and environmental scenario). However, the average value of the TBL scenario is superior to the average value of the other scenarios. This means that by focusing improvements of the corporate sustainability performance on all indicators simultaneously, companies can be more effective.

Second, greenhouse gas emissions were highlighted as an important aspect to achieve improved corporate sustainability performance. We identified 16 companies that should pay greater attention to reducing greenhouse gas emissions. This shows that the assessment of external impacts of production are primordial to achieve improved sustainability performance, as the electricity generation industry clearly plays a critical role in reducing global CO_2 emissions.

Third, our results show that the reasons for the inefficiency of the companies could be related to the characteristics of Brazilian Electricity Industry, such as few mandatory requirements for sustainability, lax regulation enforcement, and lack of social pressure.

Thus, the possible actions that can improve the companies and sector's sustainability performance can be considered exogenous actions, such as: i) focusing more on private incentives for infrastructure investments and services provided primarily for public benefit; ii) establishing plans to increase and diversify Brazilian's energy mix and reducing greenhouse gas emissions; iii) creation of new tax incentives that enable legal entities to invest a part of their payable income tax in cultural activities; and, (iv) additional efforts could be made to educate the community concerning climate change, designed to encourage conservation, fuel substitution, energy efficiency and more use of renewable.

The multidimensional construct this study provides is a rigorous way to assess and quantify sustainability performance within a system, which can be easily adapted for use in a broad range of other sectors/industries. The effectiveness of the sustainability assessment depends on the authenticity of the data/indicators, the validity of the measures, and the participation of the scientific community and stakeholders.

Considering the size of the sample analysed and the relatively small set of inputs and outputs, this study can be seen as evidential of the appropriateness of the application of DEA in combination with sustainability performance. Further study should examine a bigger network of electricity companies, or energy sector, and consider the inclusion of more indicators in the assessment. The behavior of the data should also be taken into account in future studies by monitoring the evolution of performance over time.

Finally, we believe this research and the scenario's perspective proposed can contribute to the improvement of the corporate sustainability performance for some reasons: (i) the major strengths and weaknesses can be identified and analysed in each scenario; (ii) an assessment of the overall state of sustainability and of each issue can be shown; (iii) the applied method provides a support for industry to anticipate and adapt in order to face future challenges; and, (iv) a mathematical, measurable and quantitative model facilitates a critical examination and discussion about the sustainability performance of a company.

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Appendix A

See Appendix Table A1.

Table A1
Scenarios – Appendix A shows the different perspectives regarding the importance attributed to each dimension and indicator: (i) Scenario flexibility: allowing total flexibility in the selection of the weights attached to the indicators; (ii) Scenario triple bottom line: the weights assigned in 33% to each issue; (iii) last three scenarios: social, economic and environmental: is allocated a minimum of 55% of the total weight to the sustainability issue being assessed.

i		ii		iii		iv		v	
Flexibility restriction		**Triple Bottom Line**		**Social**		**Economic**		**Environmental**	
DMU	**0**	**DMU**	**0.33**	**DMU**	**0.55**	**DMU**	**0.55**	**DMU**	**0.55**
U1	**0**	U2	**0**	U2	**0**	U6	**0**	U2	**0**
U2	**0**	U6	**0**	U6	**0**	U7	**0**	U6	**0**
U6	**0**	U7	**0**	U7	**0**	U10	**0**	U7	**0**
U7	**0**	U10	**0**	U9	**0**	U14	**0**	U10	**0**
U9	**0**	U14	**0**	U10	**0**	U15	**0**	U14	**0**
U10	**0**	U17	**0**	U11	**0**	U17	**0**	U15	**0**
U11	**0**	U15	0.06	U14	**0**	U2	0.03	U17	0.03
U14	**0**	U9	0.25	U17	**0**	U9	0.31	U9	0.1
U15	**0**	U11	0.5	U15	0.07	U13	0.38	U11	0.13
U16	**0**	U12	0.52	U13	0.1	U12	0.48	U12	0.55
U17	**0**	U13	0.59	U12	0.42	U4	0.59	U1	0.67
U13	0.04	U4	0.69	U5	0.48	U11	0.64	U5	0.68
U12	0.13	U1	0.84	U4	0.54	U1	0.66	U13	0.68
U5	0.25	U5	0.85	U3	0.59	U5	0.89	U3	0.69
U4	0.28	U3	0.92	U1	0.93	U3	0.95	U4	0.74
U3	0.4	U8	1	U8	1	U8	1	U8	0.99
U8	0.97	U16	1.01	U16	1	U16	1.02	U16	0.99
Efficient	**11**		**6**		**8**		**6**		**6**
Average	**0.1217**		**0.42534**		**0.30176**		**0.40811**		**0.36747**

Appendix B

See Appendix Table B1.

Table B1
Peers – The Appendix B presents the peers of the sample. The peers with the highest values of λ should be given more attention in benchmarking efforts intended to learn from best practices.

DMU	Peers (λ)	DMU	Peers (λ)
U1	U6(0.745), U7(0.207), U14(0.048)	U11	U7(0.95), U14(0.05)
U3	U7(0.995), U10(0.005)	U12	U7(1)
U4	U7(0.853), U17(0.147)	U13	U7(0.973), U14(0.027)
U5	U2 (0.243), U6(0.17), U7(0.586)	U15	U7(0.961), U14(0.039)
U8	U6(0.99), U14(0.01)	U16	U2 (0.467), U6(0.533)
U9	U7(0.948), U14(0.052)		

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